Nuclear Physics

Overview

One of the enduring mysteries of the universe is the nature of matter—what are its basic constituents and how do they interact to form the properties we observe? The largest contribution by far to the mass of the matter we are familiar with comes from the nuclei of atoms. The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. Although the fundamental particles that compose nuclear matter—quarks and gluons—are themselves relatively well understood, exactly how they interact and combine to form the different types of matter observed in the universe today and during its evolution remains largely unknown.

The quest to understand the properties of different forms of nuclear matter requires both theoretical and experimental efforts. Theoretical approaches are based on a description of the interactions of quarks and gluons described by a theory known as Quantum Chromodynamics (QCD). This theory is studied by scientists using today's most advanced computers. Other theoretical research that models the forces between nucleons seeks to understand and predict the structure of nuclear matter. In experimental research, scientists accumulate experimental data about the behavior of quarks and gluons as well as their composite protons, neutrons, and nuclei in a variety of settings. Most experiments today in nuclear physics use large particle accelerators that collide bits of matter together at nearly the speed of light, producing short-lived forms of matter for investigation. Comparing experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for both experimental and theoretical research. Nuclear physics seeks to understand matter a wide variety of manifestations—not just the familiar forms we see around us, but also exotic forms such as that which existed in the first moments after the Big Bang and those that exist today inside neutron stars—and to understand why matter takes on the specific forms now observed in nature.

Nuclear physics addresses three broad yet tightly interrelated scientific thrusts: Quantum Chromodynamics, Nuclei and Nuclear Astrophysics, and Fundamental Symmetries of neutrons and nuclei. Quantum Chromodynamics seeks to develop a complete understanding of how the fundamental particles that compose nuclear matter, the quarks and gluons, assemble themselves into composite nuclear particles such as protons and neutrons, how nuclear forces arise between these composite particles that lead to nuclei, and what forms of bulk strongly interacting matter can exist in nature, such as the quark-gluon plasma. Nuclei and Nuclear Astrophysics seeks to understand how protons and neutrons combine to form atomic nuclei, including some now being observed for the first time, and how these nuclei have arisen during the 13.8 billion years since the birth of the cosmos. Fundamental Symmetries seeks to develop a better understanding of fundamental interactions by studying the properties of neutrons and targeted, single focus experiments using nuclei to study whether the neutrino is its own anti-particle. Neutrinos are very light, nearly undetectable fundamental particles produced during interactions involving the weak force, through which they were first (indirectly) observed in nuclear beta decay experiments.

At the heart of the NP program are groups of highly trained scientists who conceive, plan, execute, and interpret transformative experiments. NP supports university and national laboratory scientists and a variety of international collaborations. It provides more than 90 percent of the nuclear science research funding in the U.S. with an average of 85 Ph.D. degrees granted annually to students for research supported by the program. NP research is guided by DOE's mission and priorities and helps develop the core expertise needed to achieve the goals of the NP program. National laboratory scientists work and collaborate with academic scientists and other national laboratory experimental and theoretical researchers to collect and analyze data and to construct, support, and maintain the detectors and facilities used in experiments. The national laboratories also provide state-of-the-art resources for targeted detector and accelerator R&D for future upgrades and new facilities. This research develops knowledge, technologies, and scientists to design and build next-generation NP accelerator facilities. It is also of relevance to machines being developed by other domestic and international programs.

The complementary user facilities and their associated equipment necessary to advance the U.S. nuclear science program supported by NP are large and complex, and account for about half of NP's budget. Three national scientific user facilities are currently supported, each with unique capabilities: the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL); the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF); and the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL). These facilities provide particle beams for an international user community of more than 3,000 research scientists. Approximately 38 percent of these researchers are from institutions outside of the U.S. and provide very significant benefits to leverage the U.S. program through contributed capital, human capital, experimental equipment, and intellectual contributions. Other SC programs, DOE offices (National Nuclear Security Administration [NNSA] and Nuclear Energy), Federal agencies (National Science Foundation [NSF], National Aeronautics and Space Administration [NASA], and Department of Defense), and industries also use NP user facilities to carry out their research programs. In addition, a major energy upgrade at CEBAF is underway and construction of the Facility for Rare Isotope Beams (FRIB) has begun at Michigan State University (MSU). Disposition activities continue for the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL.

Involving students in the development and construction of NP facilities and advanced instrumentation, along with the development of accelerator technology and computational techniques, supports workforce development. In addition to significant advances in discovery science, these facilities and techniques provide collateral benefits such as the creation of new technologies with broad-based applications in industry and society. The High Energy Physics program supports long-term and generic accelerator R&D that is applicable to a variety of basic and applied missions, while NP supports short- or mid-term accelerator R&D that is specific to the programmatic needs of current or planned facilities. In the process, however, technological advances developed by NP are also often relevant to other applications. For example, superconducting radio frequency (SRF) particle acceleration developed for NP programmatic missions has provided technological advances for a broad range of applications including materials research, cancer therapy, food safety, bio-threat mitigation, waste treatment, and commercial fabrication. The Office of Science programs coordinate closely on the different types of accelerator R&D activities to exploit synergies.

Highlights of the FY 2015 Budget Request

The FY 2015 requested increase of $24,435,000 over FY 2014 is driven by a $35,000,000 increase for construction and final technical design of the FRIB project, which will provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics and fundamental symmetries. Funding for university and laboratory research in Nuclear Physics will allow significant advances in nuclear structure, nuclear astrophysics, the study of matter at extreme conditions, hadronic physics, fundamental properties of the neutron and neutrinoless double beta decay. In FY 2015, NP will support ongoing core research activities at approximately the FY 2014 level. Operations of the RHIC facility are maintained, and research focuses on characterizing the perfect quark-gluon liquid discovered in collisions of relativistic heavy nuclei through research on particle flow and jet energy loss. Operations of the ATLAS facility are optimized, exploiting the new capabilities of the Californium Rare Ion Breeder Upgrade (CARIBU) and completing the campaign with the GRETINA gamma ray spectrometer. Beam development and commissioning activities ramp up at CEBAF as the 12 GeV CEBAF Upgrade project approaches completion and construction support transitions to operations funding. Support for the Isotope Development and Production for Research and Applications subprogram maintains mission readiness for the production of radioisotopes that are in short supply for research and a wide array of applications. Research investments in this subprogram aim to establish the full-scale production capability of the promising alpha-emitter, Actinium-225, to enable clinical trials for cancer therapy.

Nuclear Physics
Funding ($K)

	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Medium Energy Nuclear Physics					
Research	35,810	36,864	36,864	36,007	-857
Operations	78,123	94,493	94,493	96,050	+1,557
SBIR/STTR and Other	1,784	17,338	17,338	17,835	+497
Total, Medium Energy Nuclear Physics	**115,717**	**148,695**	**148,695**	**149,892**	**+1,197**
Heavy Ion Nuclear Physics					
Research	36,208	34,621	34,621	33,894	-727
Operations	157,021	165,072	165,072	165,072	0
Total, Heavy Ion Nuclear Physics	**193,229**	**199,693**	**199,693**	**198,966**	**-727**
Low Energy Nuclear Physics					
Research	51,118	49,180	49,180	48,450	-730
Operations	27,072	26,524	26,524	26,819	+295
Facility for Rare Isotope Beams[a]	22,000	0	0	0	0
Total, Low Energy Nuclear Physics	**100,190**	**75,704**	**75,704**	**75,269**	**-435**
Nuclear Theory					
Theory Research	32,867	38,115	38,115	35,719	-2,396
Nuclear Data Activities	6,190	7,027	7,027	7,377	+350
Total, Nuclear Theory	**39,057**	**45,142**	**45,142**	**43,096**	**-2,046**
Isotope Development and Production for Research and Applications					
Research	4,228	4,562	4,562	4,562	0
Operations	14,255	14,842	14,842	15,288	+446
Total, Isotopes	**18,483**	**19,404**	**19,404**	**19,850**	**+446**
Subtotal, Nuclear Physics	**466,676**	**488,638**	**488,638**	**487,073**	**-1,565**

[a] Funding in FY 2014 and FY 2015 for the Facility for Rare Isotope Beams (FRIB) has been moved to Construction according to the FY 2014 enacted appropriation, which established FRIB as a control point.

	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Construction					
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF	40,572	25,500	25,500	16,500	-9,000
14-SC-50, Facility for Rare Isotope Beams	0[b]	55,000	55,000	90,000	+35,000
Total, Construction	**40,572**	**80,500**	**80,500**	**106,500**	**+26,000**
Total, Nuclear Physics	**507,248**	**569,138**	**569,138**	**593,573**	**+24,435**

SBIR/STTR:

- FY 2013 transferred: SBIR: $11,163,887 ; STTR: $1,447,171
- FY 2014 projected: SBIR: $12,557,000 ; STTR: $1,794,000
- FY 2015 Request: SBIR: $13,024,000 ; STTR: $1,796,000

[b] FY 2013 funding for the Facility for Rare Isotope Beams is included in the Low Energy Nuclear Physics subprogram.

Nuclear Physics
Explanation of Major Changes ($K)

	FY 2015 vs. FY 2014 Enacted
Medium Energy Nuclear Physics: Key staff from the 12 GeV CEBAF Upgrade project continue to transition back to CEBAF operations funding to support commissioning and operations of the facility. Partially offsetting that increase is a decrease in funding for university research relative to FY 2014.	**+1,197**
Heavy Ion Nuclear Physics: Funding for university research decreases relative to FY 2014.	**-727**
Low Energy Nuclear Physics: Funding for university research decreases relative to FY 2014.	**-435**
Nuclear Theory: Funding for university research decreases relative to FY 2014. Partially offsetting the decrease is an increase in support for the National Nuclear Data program to retain key personnel.	**-2,046**
Isotope Development and Production for Research and Applications: Funding is provided to maintain mission readiness of the isotope production and processing facilities at a constant level of effort at Brookhaven, Oak Ridge, and Los Alamos National Laboratories.	**+446**
Construction: FY 2015 construction funding increases for the Facility for Rare Isotope Beams (+$35,000,000) and decreases for the 12 GeV CEBAF Upgrade project (-$9,000,000) according to the approved baseline profiles for both projects.	**+26,000**
Total, Nuclear Physics	**+24,435**

Basic and Applied R&D Coordination

Within the NP mission, unique opportunities exist and are pursued for R&D integration and coordination with other DOE Program Offices, Federal Agencies and non-Federal entities. For example, researchers from High Energy Physics, Nuclear Physics, and Advanced Scientific Computing Research (ASCR) coordinate and leverage forefront computing resources and technical expertise through the Lattice Quantum Chromodynamics (LQCD) and SciDAC projects to determine the properties of as-yet unobserved exotic particles predicted by the theory of Quantum Chromodynamics, advance progress towards a model of nuclear structure with predictive capability, and dramatically improve modeling of neutrino interactions during core collapse supernovae. The National Nuclear Data Center provides evaluated cross-section and decay data relevant to reactor design (e.g., of interest to Nuclear Energy [NE] and Fusion Energy Sciences [FES]), materials under extreme conditions (Basic Energy Sciences and FES), and nuclear forensics (National Nuclear Security Administration [NNSA], Department of Homeland Security [DHS], and Federal Bureau of Investigations [FBI]). NP has supported competitive targeted awards in Applications of Nuclear Science and Technology (ANS&T) of relevance to the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (National Institutes of Health, High Energy Physics); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening and nuclear forensics (NNSA, DHS, and FBI

R&D coordination and integration are hallmarks of the NP Isotope Development and Production for Research and Applications (Isotope) subprogram which produces commercial and research isotopes in short supply and critical for basic research and applications. It also supports research for the development of new or improved production and separation techniques of stable and radioactive isotopes. NP has taken significant steps in aligning the Federal, industrial, and research stakeholders of the Isotope Program and improving communication between the various communities. To ascertain current and future demands of the research and applied communities, NP organizes working groups, workshops, symposia, and discussions with a suite of Federal agencies and community and industrial stakeholders on a continuous basis; works collaboratively with other DOE Offices (NNSA and NE) to help ensure adequate supplies of isotopes needed for the nuclear power industry as well as for deep space exploration (NASA). The Isotope Program conducts annual Federal workshops to identify isotope demand and supply across a broad range of Federal agencies in support of research and applications within their areas of responsibility.

Program Accomplishments

Forecasting Neutron Star Cooling. Recent discoveries in x-ray astronomy and advances in theory have shown that neutron stars are unique laboratories to study matter at extreme density. A significantly improved model of the nuclear processes determining the properties of the neutron star crust now incorporates the solid and superfluid phases expected for extremely dense nuclear matter. Improved theory, modeling, and observations have led to new restrictions on key parameters, resulting in new insights and predictions for the cooling of a neutron star after intense accretion of matter from a companion star. Predictions for cooling can now be made more reliably, increasing the significance of theoretical interpretations of neutron star behavior and advancing knowledge of exotic states of dense nuclear matter.

Understanding the nearly perfect quark-gluon liquid. New experiments characterize the nearly perfect quark-gluon liquid discovered at RHIC. Recent experiments at the LHC have now confirmed RHIC's discovery that this matter behaves more as a liquid than a gas as originally thought. Comparison of key measurements at the two facilities concerning the properties of this quark-gluon liquid is critical to gain a detailed understanding of this form of matter that existed only a few millionths of a second after the birth of the universe. The results indicate that while the temperature of the matter formed at the LHC is higher than at RHIC, the matter formed at RHIC is a more perfect liquid with less resistance to flow of particles. This revelation is forging new experimental and theoretical insights into the fundamental nature of extreme states of dense nuclear matter.

How much of the Proton's Spin is carried by Gluons? New evidence from RHIC. How the spin of the proton is distributed among the quarks, antiquarks, and gluons confined inside the proton remains a fascinating open question. Although the fraction of the proton's spin carried by light quarks has been reasonably well established (about 30%), the fraction carried by gluons remains poorly understood. RHIC, the world's only high energy polarized-proton collider, is ideally suited to investigate the origin of the proton's spin. Preliminary new results indicate that gluons probably carry approximately 20% of this spin, the first indication that a large fraction of the proton's spin is carried by gluons. Data taken in 2013 at higher proton-proton collision energy of 510 GeV will be vital to further constrain the gluons' fraction of the proton's spin. The origin of the remaining 50% of the proton's spin remains to be identified, and may indicate a sizeable contribution from orbital motion of quarks and gluons inside the proton.

The Q-weak experiment at TJNAF—Determination of the Weak Charge of the Proton. The challenging "Q-weak" experiment, performed at Thomas Jefferson National Accelerator Facility, tests our present understanding of the Standard Model of electroweak interactions, and searches for evidence of new forces or particles. The experimental technique is to conduct a precise search for small effects in electron-proton scattering which indicate the violation of a fundamental symmetry of nature called parity. The degree to which parity is violated is related to a theoretical quantity called the weak charge of the proton, or Q-weak. This quantity is quite sensitive to the effects of new particles or interactions that are not described by the Standard Model of particle physics, and has the potential to confirm the accuracy of our understanding of the existence of particles and forces or point to yet undiscovered particles and forces. Results recently indicate that there is no evidence for new particles or interactions in electron-proton scattering up to the mass scale of up to 1.1 TeV, about 9 times the mass of the heaviest elementary particle known, the Higgs boson.

Mass Measurements on the r-Process Path: Results from CARIBU. Most of the light elements are produced in the cores of stars by fusion reactions. Understanding the elemental abundances resulting from supernovae requires developing models with a large number of physics inputs, such as the masses of some of the isotopes. Although stars create these isotopes readily in supernovae, producing them in the laboratory for astrophysics research is very challenging. At Argonne National Laboratory, the Californium Rare Ion Breeder Upgrade (CARIBU) now provides some isotopes of interest by capturing fragments from the fission of Californium for research and reacceleration. A nucleus of particular interest is tin-132, where the closure of two shells containing protons and neutrons results in an unusually high level of stability against nuclear decay, creating a bottleneck (waiting point) that slows down progression of r-process to heavier nuclei. First-ever simulations that incorporate information from new mass measurements at CARIBU indicate there is a significant increase in waiting time for the elements tin and antimony compared to calculations with commonly used mass models.

Long-standing question about how protons and neutrons interact resolved. A precise prediction of quantum chromodynamics (QCD) theory is a property of the proton called g_P, which accounts for the interactions of protons and neutrons via the weak force. For forty years, the measurement of this important quantity was elusive, owing to ambiguities in the underlying atomic physics needed to interpret experimental data. Two recent experiments, led by University of Washington Center for Experimental Nuclear Physics and Astrophysics (CENPA) researchers, completed part-per-million scale precision measurements of the positive muon lifetime and the negative muon lifetime. The difference in the two lifetimes leads directly to a precise determination of g_P. This unambiguous result, which avoids the experimental uncertainties in previous measurements, is in excellent agreement with theory and resolves a long-standing question about the value of this key parameter of QCD.

Nuclear Physics
Medium Energy Nuclear Physics

Description

The Medium Energy Nuclear Physics subprogram focuses primarily on experimental tests of the theory of the strong interaction, known as Quantum Chromodynamics (QCD). According to QCD, all observed nuclear particles, collectively known as hadrons, arise from the strong interaction of quarks, antiquarks, and gluons. The protons and neutrons inside nuclei are the best known examples of hadrons. QCD, although difficult to solve, predicts what hadrons exist in nature, and how they interact and decay. Specific questions addressed within this subprogram include:

- What is the internal landscape of the protons and neutrons (collectively known as nucleons)?
- What does QCD predict for the properties of strongly interacting matter?
- What governs the transition of quarks and gluons into pions (hadronic subatomic particle) and nucleons?
- What is the role of gluons and gluon self-interactions in nucleons and nuclei?

Various experimental approaches are used to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Scattering experiments are used to clarify the effects of the quark and gluon spins within nucleons, and the effect of the nuclear environment on the quarks and gluons. The subprogram also supports experimental searches for higher-mass "excited state" hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

Medium Energy Nuclear Physics supports both research and operations of the subprogram's primary research facility, CEBAF at TJNAF, as well as the RHIC spin physics research that is carried out using RHIC at BNL. CEBAF provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons from measurements of how the electrons scatter when they collide with nuclei. CEBAF also uses polarized electrons to make precision measurements to search for processes that violate a fundamental symmetry of nature, called parity, in order to search for physics beyond what is currently described by the Standard Model. These capabilities are unique in the world. The increase in beam energy provided by the 12 GeV CEBAF Upgrade opens up exciting new scientific opportunities, and will secure continued U.S. world leadership in this area of physics. Research at RHIC, which provides colliding beams of spin-polarized protons, a capability unique to RHIC, seeks to understand the origin of the spin of the proton, another important challenge in QCD. Research support for both facilities includes laboratory and university personnel needed to implement and execute experiments and to conduct the data analysis necessary to extract scientific results. Compelling special focus experiments that require different capabilities are also supported at the High Intensity Gamma Source (HIGS) at Triangle Universities Nuclear Laboratory, the Fermi National Accelerator Laboratory (Fermilab), and in Europe. Efforts are supported at the Research and Engineering Center of the Massachusetts Institute of Technology (MIT), which has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment.

The SBIR/STTR and Other category within this subprogram includes all of the mandated SBIR/STTR funding for the NP program, as well as funding to meet other NP obligations, such as the annual Lawrence Awards and Fermi Awards for honorees selected by DOE for outstanding contributions to science.

Research

Research groups at TJNAF, BNL, ANL, LANL, and LBNL, and approximately 160 scientists and 125 graduate students at 32 universities carry out research programs and conduct experiments at CEBAF, RHIC, and elsewhere, and participate in the development and fabrication of advanced instrumentation, including state-of-the-art detectors that also have applications in areas such as medical imaging instrumentation and homeland security. TJNAF staff research efforts include developing experiments, acquiring data, and performing data analysis at the three existing CEBAF experimental Halls A, B, and C. A fourth scientific research group at TJNAF is being established to exploit the experimental capabilities of the new Hall D, being constructed as part of the 12 GeV CEBAF Upgrade project. Scientists conduct research to identify and develop the opportunities and goals for next generation facilities. An active visiting scientist program at TJNAF and bridge positions with regional universities are also supported as a cost-effective approach to augmenting scientific expertise at the laboratory and boosting research experience opportunities.

ANL scientists continue targeted experiments at TJNAF and are leading an experiment at Fermilab to determine the antiquark contribution to the structure of the proton. ANL scientists are also developing a technique for making precise measurements of the electric dipole moments of laser-trapped atoms that will set limits on QCD parameters and contribute to the search for possible explanations of the excess of matter over antimatter in the universe. Research groups at BNL, LBNL, ANL, and LANL play leading roles in determining the spin structure of the proton through the development and fabrication of advanced instrumentation for RHIC, as well as contributing to data acquisition and analysis efforts. At LANL, this effort is ramped down in FY 2015 as resources there are focused on higher priority efforts. Participation of LANL scientists in the MiniBooNE experiment at Fermilab, which has shown an intriguing discrepancy between anti-neutrino and neutrino data and may unveil new physics beyond the Standard Model, are also concluded in FY 2015. Researchers at MIT and at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

Accelerator R&D research proposals from universities and laboratories specific to improving operations of current NP facilities or developing new NP facilities are evaluated by peer review through a single competition for funding under the Medium Energy and Heavy Ion subprograms.

Operations

CEBAF's polarized electron beam capabilities are used to study the contributions of quarks and gluons to the properties of hadrons by a user community with a strong international component. Accelerator Operations support is provided for the accelerator physicists at TJNAF that operate CEBAF as well as for maintenance, power costs, capital infrastructure investments, and accelerator improvements. Modest investments in high priority accelerator improvement projects are aimed at increasing the productivity, cost-effectiveness, and reliability of the facility. Support is provided for the most important efforts in developing advances in superconducting radiofrequency (SRF) technology relevant to improving operations of the existing machine. The core competency in SRF technology plays a crucial role in many DOE projects and facilities outside of nuclear physics and has broad applications in medicine and homeland security. For example, SRF research and development at TJNAF has led to improved land-mine detection techniques and carbon nanotube and nano-structure manufacturing techniques for constructing super-lightweight composites such as aircraft fuselages. TJNAF also has a core competency in cryogenics and has developed award-winning techniques that have led to more cost-effective operations at TJNAF and several other Office of Science facilities. Accelerator capital equipment investments are targeted toward instrumentation needed to support the laboratory's core competencies in SRF and cryogenics. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with the NP-supported Center for Accelerator Science at Old Dominion University. Experimental Support is provided for the scientific and technical staff as well as for materials and supplies for integration, assembly, modification, and disassembly of the large and complex CEBAF experiments. Modest capital equipment investments for experimental support at TJNAF provide scientific instrumentation for the major experiments, including data acquisition computing and supporting infrastructure.

Medium Energy Nuclear Physics

Activities and Explanation of Changes

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Research		
Efforts are focused on preparations for the new 12 GeV experimental program at TJNAF such as the implementation of instrumentation and development of the Hall D experimental group, as well as continued analysis of RHIC polarized proton beam data and 6 GeV experimental data, such as physics beyond the Standard Model of electroweak forces (Q-weak), the role of strange quarks in hadrons (HAPPEx), neutron skins in nuclei (PReX), and excited baryons (HDIce). Support for short and mid-term accelerator R&D continues. University research is increased in FY 2014 to ease the transition to fully funding research awards of $1M or less.	Efforts continue on preparations for the 12 GeV experimental program at TJNAF such as the implementation of instrumentation and development of the Hall D experimental group, as well as continued analysis of 6 GeV experimental data and RHIC polarized proton beam data. Support for short and mid-term accelerator R&D continues. ANL scientists will complete the measurement of antiquark structure of the nucleon and nucleus with the E906 Drell-Yan experiment.	Funding for university research decreases relative to FY 2014. All other research is held flat with FY 2014.

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Operations		
FY 2014 funding supports transitioning 40 FTEs from the 12 GeV CEBAF Upgrade construction project back to base operations support in order to start commissioning and operating the upgraded CEBAF machine and equipment. CEBAF is being restarted after an 18-month shutdown for installation of 12 GeV CEBAF Upgrade project components. Support increases for power and cryogens to begin pre-operations, beam study activities, and commissioning. 12 GeV CEBAF Upgrade Other Project Costs are supported in accordance with the revised baseline project profile approved in September 2013, and are essential for demonstration of project deliverables. Implementation of instrumentation for the planned scientific research program continues.	FY 2015 funding supports the transition of an additional 45 FTEs from the 12 GeV CEBAF Upgrade construction project back to base operations support. In order to support this critical transition, accelerator and instrumentation investments are constrained, and beam development is limited to the highest priority activities associated with completion of the 12 GeV CEBAF Upgrade project. Funding is provided for Other Project Costs (within project TPC) as planned as part of the 12 GeV CEBAF Upgrade project profile. The major milestone in FY 2015 will be establishing first beams to Hall D for commissioning activities.	An increase of approximately $7 million is needed to support the 45 operations staff FTEs transitioning from the 12 GeV Upgrade project back to the base operations budget. This increase for the high priority transition of staff has been partially offset by redirecting funds from other activities, such as facility experimental equipment, accelerator improvement projects, accelerator R&D, laboratory GPP, materials and supplies, and beam development operations.
SBIR/STTR and Other		
Support is provided for NP’s required contribution to the SBIR/STTR programs, as well as other DOE and Office of Science obligations, such as the annual Fermi and Lawrence awards.	Support is provided for NP’s required contribution to the SBIR/STTR programs, as well as other DOE and Office of Science obligations.	The SBIR/STTR funding set-aside of 3.2% in FY 2014 increases to 3.3% in FY 2015.

Heavy Ion Nuclear Physics

Description

The Heavy Ion Nuclear Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures, directed primarily at answering the overarching questions within the Quantum Chromodynamics (QCD) scientific thrust, including:

- What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
- What governs the transition of quarks and gluons into pions and nucleons?
- What determines the key features of QCD and their relation to the nature of gravity and space-time?

At the Relativistic Heavy Ion Collider (RHIC) facility, scientists continue to pioneer the study of condensed quark-gluon matter at the extreme temperatures characteristic of the infant universe. The intellectual goal is to explore and understand unique manifestations of QCD in this many-body environment and their influence on the universe's evolution. Complementary research capability is also provided at the Large Hadron Collider (LHC) at CERN. In the debris of collisions at RHIC and at the LHC, researchers have seen signs of the same quark-gluon plasma that is believed to have existed shortly after the Big Bang. With careful measurements, scientists are accumulating data that offer insights into the processes early in the creation of the universe, and how protons, neutrons, and other bits of normal matter developed from that plasma. Important avenues of investigation are directed at learning more about the physical characteristics of the quark-gluon plasma including exploring the energy loss mechanism for quarks and gluons traversing the plasma, determining the speed of sound in the plasma and locating the critical point for the transition between the plasma and normal matter.

The RHIC facility places heavy ion research at the frontier of nuclear physics. RHIC serves two large-scale international experiments called PHENIX and STAR. Operation of RHIC in FY 2015 will continue to take advantage of the increase in the heavy ion beam collision rate using the stochastic cooling systems completed in FY 2013 and the Electron Beam Ion Source (EBIS). New and ongoing detector upgrades coupled with the enhanced collision rate will contribute further scientific results and understanding. The RHIC facility is uniquely flexible, providing a full range of colliding nuclei at variable energies spanning the transition to the new state of matter discovered at RHIC. Short and mid-term accelerator R&D is conducted at RHIC in a number of areas including the cooling of high-energy hadron beams based on a new concept called Coherent Electron Cooling; high intensity polarized electron sources; and high-energy, high-current energy recovery linear (ERL) accelerators. The RHIC facility is used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Collaboration in the heavy ion program at the LHC at CERN provides U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infant universe. Data collected by the ALICE, CMS, and ATLAS detectors confirm that the same quark-gluon plasma is seen at the higher energy. In addition to playing a lead role in the fabrication and operation of a large electromagnetic calorimeter detector installed in FY 2010 in the ALICE experiment, U.S. researchers are making important scientific contributions to the emerging results from all three LHC experiments.

<u>Research</u>

Heavy ion research groups at BNL, LBNL, LANL, ORNL, and LLNL, and about 120 scientists and 100 graduate students at 28 universities are supported to analyze data from RHIC and participate in a modest program at the LHC.

The university and national laboratory research groups provide the scientific personnel and graduate students needed for running the RHIC and LHC heavy ion experiments; analyzing data; publishing results; conducting R&D of next-generation detectors; planning for future experiments; and designing, fabricating, and operating the RHIC and LHC heavy ion detectors. BNL also provides project management oversight for the fabrication of the STAR Heavy Flavor Tracker (HFT) MIE. BNL and LBNL provide computing infrastructure for petabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. At LBNL, a large scale computational system, the Parallel Distributed Systems Facility (PDSF), is a major resource used for the analysis of RHIC and LHC data in alliance with the National Energy Research Scientific Computing Center (NERSC), which is supported by the SC's Advanced Scientific Computing Research program. LLNL computing resources are also used for LHC data analysis.

Accelerator R&D research proposals for short and mid-term accelerator R&D from universities and laboratories specific to improving operations of current NP facilities or developing new NP facilities are evaluated by peer review through a single competition for funding under the Heavy Ion and Medium Energy subprograms.

Operations

Support is provided for the operations, power costs, capital infrastructure investments, and accelerator improvement projects of the RHIC accelerator complex at BNL. This includes the Electron Beam Ion Source (EBIS), Booster, and the Alternating Gradient Synchrotron (AGS) accelerators that together serve as the injector for RHIC. RHIC operations allow for parallel and cost-effective operations of the Brookhaven Linac Isotope Producer Facility (BLIP), supported by NP for the production of research and commercial isotopes critically needed by the Nation, and of the NASA Space Radiation Laboratory Program for the study of space radiation effects applicable to human space flight. Through operations of the RHIC complex, important core competencies are nurtured in accelerator physics techniques to improve RHIC performance and support the NP mission. These core competencies provide collateral benefits to applications in industry, medicine, homeland security, and other scientific projects outside of NP. RHIC accelerator physicists are leading the effort to address technical feasibility issues of relevance to a possible next-generation collider for the NP program, including beam cooling techniques and energy recovery linacs. These physicists also play an important role in the training of next generation accelerator physicists, with support of graduate students and post-doctoral associates.

Heavy Ion Nuclear Physics

Activities and Explanation of Changes

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Research		
Researchers are participating in the collection and analysis of data from RHIC to investigate the interaction of heavy quarks with the quark gluon plasma, and in the conduct of R&D for innovative detector designs and planning for future experiments. NP provides scientific leadership to the international heavy ion experiment ALICE, and the heavy ion research components of the CMS and ATLAS experiments; the LHC runs in heavy ion mode for 1 month per year, after HEP running is concluded. NP also provides related funding to the LHC for U.S. commitments for management and operating costs of the heavy ion program. The fabrication of the STAR Heavy Flavor Tracker detector, an experiment to take advantage of RHIC's luminosity, is on track for early completion and utilization in RHIC's Run 14. Mid- and short-term accelerator R&D is also supported. University research is increased in FY 2014 to ease the transition to fully funding research awards of $1M or less.	Researchers will continue to participate in the collection and analysis of data from RHIC with newly completed scientific instrumentation to study collisions with a range of light and heavy nuclei to better understand the initial conditions in heavy ion collisions, and in the conduct of limited R&D for innovative detector designs and planning for future experiments. NP provides scientific leadership to the international ALICE, CMS, and ATLAS experiments, as well as providing the required funding to the LHC for U.S. commitments for management and operating costs. Mid- and short-term accelerator R&D relevant to NP programmatic needs is also supported. The STAR Heavy Flavor Detector major item of equipment is completed.	Funding for university research decreases relative to FY 2014. All other research is held flat with FY 2014.

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Operations		
RHIC operations will provide for 2,770 beam hours (approximately 22 weeks and 68 percent utilization) in support of the planned RHIC research program. Efforts continue to increase the heavy ion and proton-proton beam luminosity for enhanced scientific productivity. Newly completed electron lenses should improve polarized proton luminosity. A 56 MHZ superconducting storage cavity is being installed at RHIC to increase the RHIC luminosity by about 30%.	RHIC operations will provide for 2,770 beam hours (approximately 22 weeks and 68 percent utilization) in support of the planned RHIC research program that takes advantage of dramatic improvements in collider performance and versatility made possible by recent RHIC upgrades. Funds for experimental equipment, accelerator R&D, and materials and supplies are reduced in FY 2015 in order to optimize running levels.	RHIC Operations are held flat with FY 2014.

Nuclear Physics
Low Energy Nuclear Physics

Description

The Low Energy Nuclear Physics subprogram focuses on answering the overarching questions associated with Nuclei and Nuclear Astrophysics and with Fundamental Symmetries, two areas identified as scientific priorities in the 2007 Long Range Plan for Nuclear Science.[a]

Questions associated with Nuclei and Nuclear Astrophysics include:

- What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?
- What is the origin of simple patterns in complex nuclei?
- What is the nature of neutron stars and dense nuclear matter?
- What is the origin of the elements in the cosmos?
- What are the nuclear reactions that drive stars and stellar explosions?

This subprogram addresses these questions by supporting research to develop a comprehensive description of nuclei using beams of stable and rare isotopes to yield new insights and reveal new nuclear phenomena. The subprogram also measures the cross sections of the nuclear reactions that power stars and lead to spectacular stellar explosions, which are responsible for the synthesis of the elements.

Questions addressed in Fundamental Symmetries of neutrons and nuclei (which uses neutrinos and neutrons as primary probes) include:

- What experimental approach for a next generation, ton-scale neutrino-less double beta day detector is capable of achieving the sensitivity necessary to determine if the neutrino is it own anti-particle?
- Is there evidence from the electric-dipole moments of atomic nuclei and the neutron that our current understanding of the fundamental laws governing nuclear physics is incomplete?
- Does evidence for parity violation in electron scattering and possible lepton number violation in the decay of nuclei indicate forces present at the dawn of the universe that disappeared from view as the universe evolved?

This subprogram addresses these questions through precision measurements primarily with neut rons and neutrinos. Beams of cold and ultracold neutrons are used to study fundamental properties of neutrons. Precision studies to observe or set a limit on violation of time-reversal invariance—the principle that the physical laws should not change if the direction of time is reversed—in nucleonic, nuclear, and atomic systems investigate fundamental questions in nuclear physics, astrophysics, and cosmology.

The ATLAS national scientific user facility has been pivotal in making progress in Nuclear Structure and Nuclear Astrophysics, serving a combined international community of approximately 400 scientists. ATLAS provides high-quality beams of all the stable elements up to uranium as well as selected beams of short-lived nuclei for experimental studies of nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics.

HRIBF ceased operations in 2012. Disposition activities of this facility continue in FY 2015. Analysis of data from HRIBF on exotic nuclei that do not normally exist in nature and reactions of interest to nuclear astrophysics and isotope production is continuing.

NP supports the LBNL 88-Inch Cyclotron jointly with the National Reconnaissance Office (NRO) and the U.S. Air Force (USAF). Accelerator operations are supported at two university Centers of Excellence with specific goals and unique physics

[a] http://science.energy.gov/~/media/np/nsac/pdf/docs/nuclear_science_low_res.pdf

programs: the Cyclotron Institute at Texas A&M University (TAMU) and accelerator facilities at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University. A third university center, the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, provides unique expertise and capabilities for instrumentation development.

Progress in nuclear structure and nuclear astrophysics depends increasingly upon the availability of rare isotope beams. While ATLAS has some capabilities for these studies, one of the highest priorities for the NP program is support for the construction of a facility with world-leading capabilities for short-lived radioactive beams, the Facility for Rare isotope Beams (FRIB). FRIB is a next-generation machine that will advance understanding of rare nuclear isotopes and the evolution of the cosmos by providing beams of rare isotopes with neutron and proton numbers far from those of stable nuclei in order to test the limits of nuclear existence.

Research

Low Energy research groups are supported at ANL, BNL, LBNL, LANL, LLNL, PNNL, and ORNL, as well as 46 university grants. The subprogram funds about 170 Ph.D. scientists and nearly 100 graduate students at universities and national laboratories. About two-thirds of the supported scientists conduct nuclear structure and astrophysics research primarily using specialized instrumentation at the ATLAS national user facility as well as smaller accelerator facilities at two university-based Centers of Excellence. The remaining groups conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source, double beta-decay experiments such as the Cryogenic Underground Observatory for Rare Events (CUORE) experiment at Gran Sasso Laboratory in Italy and the Majorana Demonstrator R&D effort at the Sanford Underground Research Facility in Lead, South Dakota, a measurement of the neutrino mass with the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany, and limited R&D to measure the neutron electric dipole moment.

Operations

ATLAS provides stable and selected radioactive beams and utilizes specialized instrumentation for scientists to conduct research on nuclear structure and nuclear astrophysics. It is the premiere stable beam facility in the world. The Californium Rare Ion Breeder Upgrade (CARIBU) at ATLAS provides targeted unique capabilities to produce radioactive ion beams until FRIB, which will be the most advanced facility for rare ion beams in the world, becomes operational in the next decade. The ATLAS facility nurtures a core competency in accelerator science with superconducting radio frequency cavities for heavy ions that are relevant to the next generation of high-performance proton and heavy-ion linacs. This competency is important to the Office of Science mission and international stable and radioactive ion beam facilities.

Low Energy Nuclear Physics

Activities and Explanation of Changes

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Research		
University and laboratory nuclear structure and nuclear astrophysics efforts focus on research at ATLAS, university Centers of Excellence, and support for the development of instrumentation for FRIB. Implementation of scientific instrumentation for neutrino physics and R&D for a next generation double beta decay experiment continue with the start of commissioning of the prototype module for the Majorana Demonstrator. Support is also provided for operations, maintenance, and enhancement of the GRETINA detector; operations of the KATRIN experiment; and operation costs for the CUORE MIE. The neutron program at the FNPB focuses on the fundamental properties of the neutron, and R&D on the feasibility of setting a world leading limit on the electric dipole moment of the neutron (nEDM). University research is increased in FY 2014 to ease the transition to fully funding research awards of $1M or less.	University and laboratory nuclear structure and nuclear astrophysics efforts focus on research at ATLAS, three university Centers of Excellence, and limited support for highest priority development efforts for instrumentation at FRIB. Commissioning of the Majorana Demonstrator continues and data taking is initiated. The international CUORE major item of equipment is completed. Support continues for the GRETINA detector maintenance and operations and KATRIN operations. The neutron program at the FNPB continues R&D on the feasibility of setting a world leading limit on nEDM.	Funding for university research decreases relative to FY 2014. All other research activities are held flat with FY 2014.

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Operations		
ATLAS will deliver 3,500 hours (about 22 weeks) of beam time, 83% of optimal operations due to planned downtime for installation of upgrades. A new cryomodule is being installed to provide accelerated stable beams and beams from CARIBU with increased intensity. Accelerator and capital investments continue the energy and efficiency upgrade and the development of an electron beam ion source. Funding continues for the implementation of equipment disposition activities at HRIBF.	ATLAS will provide an estimated 5,900 hours (about 37 weeks) of beam time, 95% of optimal operations. The Electron Beam Ion Source AIP will be commissioned at ATLAS. Funding continues for equipment disposition activities at HRIBF.	A modest increase will maintain critical operations personnel at the ATLAS scientific user facility.

Description

The Nuclear Theory subprogram provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science subprograms and to advance new ideas and hypotheses that identify potential areas for future experimental investigations. Nuclear Theory addresses all three of NP's scientific thrusts. One major theme of theoretical research is the development of an understanding of the mechanisms and effects of quark confinement and deconfinement. A quantitative description of these phenomena through QCD is one of this subprogram's greatest intellectual challenges. New theoretical and computational tools are also being developed to describe nuclear many-body phenomena; these approaches will likely also see important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements (e.g., via supernovae) and the consequences that neutrino masses have for nuclear astrophysics.

This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington. A second round of five-year topical collaborations within the university and national laboratory communities to address high-priority topics in nuclear theory that merit a concentrated theoretical effort will be competed at the end of FY 2015 when the first round of collaborations comes to an end. The Nuclear Theory subprogram also operates the Nuclear Data program through the National Nuclear Data Center (NNDC), which collects, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. The extensive nuclear databases maintained and continually updated by the Nuclear Data program are an international resource consisting of carefully organized scientific information gathered from over 100 years of worldwide low-energy nuclear physics experiments.

Much of the research supported by the Nuclear Theory subprogram requires extensive access to leading-edge supercomputers. One area that has a particularly pressing demand for large, dedicated computational resources is LQCD. LQCD calculations are critical for understanding and interpreting many of the experimental results from RHIC, LHC, and CEBAF. A new joint five-year HEP/NP computer hardware project "LQCD-ext II" will be supported starting in FY 2015 to continue providing specialized computing resources for LQCD research, following the previous joint efforts that address the computational requirements of LQCD research. Both HEP and NP require this type of computing capability in order to conduct simulations that address their distinct science programs. The partnering of the two Offices ensures effective coordination to maximize the leverage available for this activity from the infrastructure and intellectual capital of both programs and to prevent duplication of effort on resource-intensive caculations inherently central to quantum chromodyanics and particle physics research.

SciDAC, a collaborative program with ASCR that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities at the current technological limits, is also supported within this subprogram. The NP SciDAC program operates on a five year cycle, and supports computationally intensive research projects jointly with other SC and DOE offices in areas of mutual interest. SciDAC-3 awards were made in FY 2012 and will continue through FY 2016.

Theory Research

The Nuclear Theory subprogram supports the research programs of approximately 160 university scientists and 120 graduate students at 45 universities, as well as nuclear theory groups at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF). This research has the goals of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research. It is aligned with the experimental program through the program performance milestones established by the Nuclear Sciences Advisory Committee (NSAC). Three topical collaborations [JET (QCD in the heavy-ion environment); NuN (neutrinos and nucleosynthesis in hot and dense matter); and TORUS (low-energy nuclear reactions for unstable isotopes)] will receive their last year of funding in FY 2014. Based on the success and community support of this program, a new round of 5-year topical collaborations to bring together theorists to address specific high-priority theoretical challenges is planned to be competed late in FY 2015.

Nuclear Data Activities

The Nuclear Data effort involves the work of several national laboratories and universities, and is guided by the DOE-managed National Nuclear Data Center (NNDC) at BNL. The NNDC coordinates the work of the U.S. Nuclear Data Network, a group of DOE-supported individual nuclear data professionals located in universities and national laboratories that perform assessments, validate and estimate uncertainties, and develop modern online dissemination capabilities. The databases developed and maintained by the Nuclear Data program cover over 100 years of nuclear science research with between 1,500 and 6,000 nuclear data retrievals on a daily basis. The NNDC participates in the International Data Committee of the IAEA and is an important national and international resource.

Nuclear Theory

Activities and Explanation of Changes

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Theory Research		
Funding supports university and laboratory theoretical efforts for the interpretation of experimental results obtained at NP facilities, including nuclear structure computations with an optimized nuclear force model. Efforts will continue to focus on the research program at the upgraded CEBAF 12 GeV facility, the research program at the future FRIB facility, and topics related to fundamental symmetries. Funding supports ongoing research efforts, the SciDAC-3 grants, and the final year of funding for the topical theory collaborations, as planned. University research is increased in FY 2014 to ease the transition to fully funding research awards of $1M or less.	Funding supports the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, including multi-dimensional fluctuating fluid-dynamical calculations to describe relativistic nuclear collisions. Efforts focus on nucleon and nuclear structure, spectroscopy, and reactions in preparation for the research program at the upgraded CEBAF 12 GeV facility, the research program at the planned FRIB facility, and on topics related to fundamental symmetries. Funding supports ongoing research efforts, the SciDAC-3 grants, and the LQCD ext-II computing project.	Funding for university research decreases relative to FY 2014. All other research is held flat with FY 2014.

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Nuclear Data Activities		
NNDC efforts focus on updating online databases containing experimental and evaluated nuclear structure data, nuclear reaction cross sections, and nuclear science literature and on maintaining computing infrastructure needed to support important efforts across the national Nuclear Data program. Specifically, nuclear structure and decay data will be evaluated and compiled in the Evaluated Nuclear Structure Data File (ENSDF) database, and bibliographic information and nuclear reaction data will be compiled in the Nuclear Science References (NSR) and Cross-Section Information Standard Retrieval System (CSISRS) databases.	Efforts continue to focus on updating online databases containing experimental and evaluated nuclear structure data, nuclear reaction cross sections, and nuclear science literature and on maintaining computing infrastructure needed to support important efforts across the National Nuclear Data program. Specifically, a new XML-based nuclear data structure model will be developed and incorporated into databases.	Funding is provided to retain NNDC staffing in order to support needed program advances.

Nuclear Physics
Isotope Development and Production for Research and Applications

Description

The Isotope Development and Production for Research and Applications subprogram (Isotope Program) supports the production, distribution, and development of production techniques for radioactive and stable isotopes in short supply and critical to the Nation. Isotopes are commodities of strategic importance for the Nation that are essential for energy exploration and innovation, medical applications, national security, and basic research. The goal of the program is to make key isotopes more readily available to meet U.S. needs. To achieve this goal, the program incorporates all capabilities, including facilities and technical staff, required for supply chain management of critically important isotopes. The subprogram also supports R&D efforts associated with developing new and more cost-effective and efficient production and processing techniques, and on the production of isotopes needed for research purposes. The R&D activities also provide collateral benefits for training, contributing to workforce development, and helping to ensure a future U.S.-based expertise in the fields of nuclear chemistry and radiochemistry. These disciplines are foundational not only to radioisotope production but to many other critical aspects of basic and applied nuclear science as well.

The Isotope Program operates a revolving fund to maintain its financial viability by utilizing a combination of appropriations and revenues from the sale of isotopes and services. These resources are used to maintain the staff, facilities, and capabilities at user-ready levels and to support peer-reviewed research and development activities related to the production of isotopes. Isotopes sold to commercial customers are priced to recover the full cost of production, or the market price (whichever is higher). Research isotopes are sold at reduced cost to ensure high priority research requiring them does not become cost prohibitive. Investments in new capabilities are made to meet the growing demands of the Nation and foster future research in applications that will support national security and the health and welfare of the public.

Isotopes are critical national resources used to improve the accuracy and effectiveness of medical diagnoses and therapy, enhance national security, improve the efficiency of industrial processes, and provide precise measurement and investigative tools for materials, biomedical, environmental, archeological, and other research. Some examples are:

- strontium-82 use for cardiac imaging;
- californium-252 for well logging, medicine, homeland defense, and energy security;
- germanium-68 use for calibrating the growing number of positron imaging scanners;
- berkelium-249, californium-251, and curium-244 use as targets for discovery of new superheavy elements;
- selenium-75 use in industrial radiography;
- actinium-225, bismuth-213, lead-212, thorium-227, and radium-223 use in cancer and infectious disease therapy research;
- nickel-63 use in molecular sensing devices and helium-3 (He-3) as in neutron detectors, both for applications in homeland defense;
- strontium-90 and cobalt-60 use for cancer therapy;
- arsenic-73 use as a tracer for environmental research; and
- silicon-32 use in oceanographic studies related to climate modeling.

Stable and radioactive isotopes are vital to the mission of many Federal agencies including the National Institutes of Health (NIH), the National Institute of Standards and Technology, the Environmental Protection Agency, the Department of Agriculture, the Department of Homeland Security (DHS), NNSA, and DOE Office of Science programs. NP continues to work in close collaboration with these organizations to develop strategic plans for isotope production and to establish effective communication to better forecast isotope needs and leverage resources. For example, a five-year production strategy has been generated with the NIH that identifies the isotopes and projected quantities needed by the medical community in the context of the Isotope Program production capabilities. In addition, NP initiated an annual workshop, attended by representatives of all Federal agencies that require stable and radioactive isotopes to support research and applications within their realms of responsibility, to provide a comprehensive assessment of national needs for isotope products and services. Another example is participation in the White House Office of Science and Technology Policy (OSTP) working group on molybdenum-99 (Mo-99). While the Isotope Program is not responsible for the production of Mo-99, it recognizes the importance of this isotope for the Nation as a diagnostic in cardiac imaging and is working closely with NNSA, the lead entity responsible for domestic Mo-99 production, and is offering technical and management support. NP participates in the international High-Level Group on the Security of Supply of Medical Isotopes lead by the Organisation for Economic Co-operation and Development (OECD). NP participates in the Certified Reference Material Working Group which assures material availability for nuclear forensics applications that support national security missions. NP plays a lead role in a federal working group on the He-3 supply issue involving NNSA, DHS, the Department of Defense, NIH, and many other agencies. The objective of the working group is to ensure that the limited supply of He-3 will be distributed to the highest priority applications and basic research. The Isotope Program packages and distributes the isotope. The Isotope program plays a lead role in working with all of the Federal agencies in forecasting demand for the gas and its allocation.

The National Isotope Development Center (NIDC) is a virtual center that interfacing with the user community and manages the coordination of isotope production across the facilities and business operations involved in the production, sale, and distribution of isotopes. The NIDC includes the Isotope Business Office, which is located at ORNL.

Research

Research is supported to develop new or improved production or separation techniques for high priority isotopes in short supply. Examples of isotope research required to meet national needs include positron-emitting radionuclides to support the rapidly growing area of medical imaging using positron emission tomography (PET), isotopes supporting medical research used to diagnose and treat diseases spread through acts of bioterrorism, alpha-emitting radionuclides exhibiting great potential in disease treatment, research isotopes for various biomedical applications, enriched stable isotopes, and alternative isotope supplies for national security applications and advanced power sources. Priorities in research isotope production are informed by guidance from NSAC. One of the high priorities is to conduct R&D aimed at re-establishing a U.S. capability for stable isotope production. Isotope Program research also provides training opportunities for workforce development in the areas of nuclear chemistry and radiochemistry. These disciplines are essential to the long-term health of the fields of radioisotope production and applications.

Operations

The Isotope Program is steward of the Isotope Production Facility (IPF) at Los Alamos National Laboratory (LANL) and the Brookhaven Linac Isotope Producer (BLIP) facility at BNL and provides support for hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. Facilities at other sites are used as needed, such as the Idaho National Laboratory reactor for the production of cobalt-60, the Pacific Northwest National Laboratory for processing and packaging strontium-90, the Y-12 National Security Complex for processing and packaging lithium-6 and lithium-7, and the Savannah River Site for the extraction and distribution of helium-3.

Isotope Development and Production for Research and Applications

Activities and Explanation of Changes

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Research		
Support maintains research and development competitive awards at universities and national laboratories, and core laboratory research groups at LANL, BNL, and ORNL. Development of production techniques for alpha-emitters is a high priority, as is R&D aimed at re-establishing a domestic capability for research quantities of stable isotopes. Development of a new target design is conducted to re-establish cobalt-57 production for the medical community.	Support maintains research and development competitive awards and laboratory research groups at LANL, BNL, and ORNL. Development of production techniques for alpha-emitters will continue to be a high priority, as will R&D aimed at re-establishing a domestic capability for research quantities of stable isotopes. Development will be completed for a 100 mA ion source and ion optics for production scale electromagnetic stable isotope separation, which is critical for the re-establishment of enriched stable isotope production in the United States.	Research is held flat with FY 2014.

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
Operations		
Support continues at constant level of effort for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. National laboratory operations are focused on essential activities required to maintain aging facilities in operational condition. Funding is also provided to support university-based operations in support of isotope production. The isotopes produced will represent a balance of commercial isotopes and high priority research isotopes identified by NSAC and the Federal workshop held January 2012. A major milestone in FY 2014 will be completion of radiological facility equipment refurbishment at HFIR to support production of californium-252 to meet production commitments for FY 2015 through FY 2017.	Support will continue for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. National laboratory operations are focused on essential activities required to maintain aging facilities in operational conditions. Funding is provided to support university-based operations in support of isotope production. The isotopes produced will represent a balance of commercial isotopes and high priority research isotopes, with prioritization informed by NSAC and the Federal workshop in September 2013. A major milestone will be the development of a rubidium metal target at the IPF for increased production of strontium-82 for medical heart imaging.	Funding increases to maintain a constant level of effort for the Isotope Production Facility, the Brookhaven Linac Isotope Producer, and processing capabilities at ORNL, BNL, and LANL, and the NIDC.

Description

Funding in this subprogram provides for design and construction needed to meet overall objectives of the Nuclear Physics program. Currently NP is supporting two projects.

The 12 GeV CEBAF Upgrade at TJNAF, which was identified in the 2007 NSAC Long-Range Plan as the highest priority for the U.S. Nuclear Physics program, will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. A full assessment of the project baseline was conducted in FY 2013 as a result of the FY 2012 appropriation, which provided $50,000,000, $16,000,000 less than the baseline profile, as well as technical challenges. A revised baseline was approved in September 2013.

The Facility for Rare Isotope Beams is funded through a cooperative agreement with Michigan State University and was established as a control point in the FY 2014 appropriation. Prior to that time, funding for the project was provided within the Low Energy subprogram. FRIB will provide intense beams of rare isotopes for world-leading research opportunities in nuclear structure, nuclear astrophysics, and fundamental symmetry studies that will advance knowledge of the origin of the elements and the evolution of the cosmos. It offers a facility for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a broadly applicable theory of the structure of nuclei will emerge.

Construction

Activities and Explanation of Changes

FY 2014 Enacted	FY 2015 Request	Explanation of Changes FY 2015 vs. FY 2014 Enacted
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF		
The new cryomodules will be installed in the accelerator tunnel and commissioning activities will be initiated; experimental equipment will also be procured, fabricated, and installed in support of the upgrade effort in Halls B and C and the new Hall D.	Experimental equipment in Halls B, C, and D will continue to be procured, fabricated, installed, and commissioned. Project work associated with civil and accelerator construction will be minimal in FY 2015 with accelerator commissioning scheduled to be complete in FY 2015. CD-4A (Approve Accelerator Project Completion and Start of Operations for the 12 GeV Project) is planned for the first quarter of FY 2015. The project is working towards completion by the end of FY 2017.	The decrease reflects the approved baseline profile for the project.
14-SC-50, Facility for Rare Isotope Beams (FRIB)		
Civil construction and major procurements commenced following enactment of the appropriation. CD-3b (Approve Start of All Construction) is planned for the fourth quarter of FY 2014 and will allow construction of technical components as well as civil construction.	Civil and technical construction, major procurements, and fabrication of components as required under the baselined FRIB scope continue.	Federal funding ramps up for continued FRIB construction according to the Performance Baseline and funding profile established in August 2013.

Nuclear Physics
Performance Measure

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program. For more information, refer to the Department's FY 2013 Annual Performance Report. The following table shows the targets for FY 2013 through FY 2015.

	FY 2013	FY 2014	FY 2015
Performance Goal (Measure)	**NP Facility Operations—Average achieved operation time of NP user facilities as a percentage of total scheduled annual operation time.**		
Target	≥ 80%	≥ 80%	≥ 80%
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**NP Construction/MIE Cost & Schedule—Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.**		
Target	< 10%	< 10%	< 10%
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		

	FY 2013	FY 2014	FY 2015
Performance Goal (Measure)	**Conduct fundamental research to discover, explore, and understand all forms of nuclear matter.**		
Target	Complete initial measurements with high resolving power tracking array, GRETINA, for sensitive studies of structural evolution and production of superheavy elements.	Perform mass measurements and nuclear reaction studies to infer weak interaction rates in nuclei in order to constrain models of supernovae and stellar evolution.	Measure bulk properties, particle spectra, correlations and fluctuations in gold + gold collisions at Relativistic Heavy Ion Collider (RHIC) to search for evidence of a critical point in the Quantum Chromodynamics (QCD) matter phase diagram.
Result	Met	TBD	TBD
Endpoint Target	Increase the understanding of the existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe.		

Nuclear Physics Capital Summary ($K)

	Total	Prior Years	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs FY 2014 Enacted
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	16,603	18,937	18,937	16,428	-2,509
General plant projects (GPP)	n/a	n/a	2,500	2,500	2,500	2,000	-500
Accelerator improvement projects (AIP)	n/a	n/a	4,200	4,370	4,370	4,249	-121
Total, Capital Operating Expenses	**n/a**	**n/a**	**23,303**	**25,807**	**25,807**	**22,677**	**-3,130**

	Total	Prior Years	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs FY 2014 Enacted
Capital Equipment							
Major items of equipment (TEC over $2 million)							
STAR Heavy Flavor Tracker, BNL (TPC $15,480)	15,200	6,800	3,730	0	0	0	0
Other capital equipment projects under $2 million TEC	n/a	n/a	12,873	18,937	18,937	16,428	-2,509
Total, Capital Equipment	**n/a**	**n/a**	**16,603**	**18,937**	**18,937**	**16,428**	**-2,509**

STAR Heavy Flavor Tracker (HFT), BNL: This MIE will fabricate a high-precision tracking and vertexing device based on ultra-thin silicon pixel and pad detectors in the STAR detector. It received CD-2/3 approval in October 2011. The project is scheduled for completion in FY 2015, but is on track to be completed early.

	Total	Prior Years	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs FY 2014 Enacted
General Plant Projects							
General plant projects under $5 million TEC	n/a	n/a	2,500	2,500	2,500	2,000	-500
Accelerator Improvement Projects (AIP)							
RHIC Low Energy Electron Cooling	9,900	0	1,300	2,300	2,300	2,300	0
Other projects under $5 million TEC	n/a	n/a	2,900	2,070	2,070	1,949	-121
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**4,200**	**4,370**	**4,370**	**4,249**	**-121**

Nuclear Physics Construction Projects Summary ($K)

	Total	Prior Years	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs FY 2014 Enacted
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF							
TEC	310,500	220,428	40,572	25,500	25,500	16,500	-9,000
OPC	27,500	10,500	2,500	4,500	4,500	4,500	0
TPC[a]	338,000	230,928	43,072	30,000	30,000	21,000	-9,000
14-SC-50, Facility for Rare Isotope Beams							
DOE TPC	635,500[b]	51,000[c]	22,000[c]	55,000	55,000	90,000	+35,000
Total, Construction (TPC)	**n/a**	**n/a**	**65,072**	**85,000**	**85,000**	**111,000**	**+26,000**

Nuclear Physics Funding Summary ($K)

	FY 2013 Current	FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Research	162,691	170,369	166,009	-4,360
Scientific User Facilities Operations	249,573	276,811	278,663	+1,852
Other Facility Operations	24,898	24,120	24,566	+446
Projects				
Major Items of Equipment	3,730	0	0	0
Facility for Rare Isotope Beams	22,000	55,000	90,000	+35,000
12 GeV Upgrade TEC	40,572	25,500	16,500	-9,000
Total Projects	66,302	80,500	106,500	+26,000
Other[d]	3,784	17,338	17,835	+497
Total Nuclear Physics	**507,248**	**569,138**	**593,573**	**+24,435**

[a] The TPC reflects the revised baseline that was approved in September 2013.

[b] This is the DOE TPC; MSU's cost share is $94,500,000 bringing the total project cost to $730,000,000. FRIB is funded with operating dollars through a Cooperative Agreement financial assistance award with a work breakdown structure (WBS) that is slightly different from typical federal capital assets. The WBS totals $730,000,000 including MSU's cost share. Because the WBS scope is not pre-assigned to DOE or MSU funds, DOE's baseline of $635,500,000 can not be broken down between TEC and OPC.

[c] The PY and FY 2013 funding was provided within the Low Energy subprogram. The FY 2014 appropriation established FRIB as a control point.

[d] Includes SBIR/STTR funding in FY 2014–FY 2015.

Scientific User Facility Operations ($K)

	FY 2013 Current	FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
CEBAF (TJNAF)[a]	**$89,907**	**$106,237**	**$107,025**	**+$788**
Achieved operating hours	0	N/A	N/A	
Planned operating hours	0	0	0	0
Optimal hours	0	0	0	0
Percent of optimal hours	N/A	N/A	N/A	
Unscheduled downtime	N/A	N/A	N/A	
Number of users	1,260	1,245	1,235	-10
RHIC (BNL)	**$165,831**	**$172,079**	**$172,079**	**0**
Achieved operating hours	2,238	N/A	N/A	
Planned operating hours	2,100	2,770	2,770	0
Optimal hours	4,100	4,100	4,100	0
Percent of optimal hours	54.6%	67.6%	67.6%	
Unscheduled downtime	17.2%	N/A	N/A	
Number of users	1,200	1,200	1,200	0
ATLAS (ANL)[b]	**$21,098**	**$21,887**	**$22,182**	**+$295**
Achieved operating hours	4,104	N/A	N/A	
Planned operating hours	3,500	3,500	5,900	+2,400
Optimal hours	4,200	4,200	6,200	+2,000
Percent of optimal hours	97.7%	83.3%	95.2%	
Unscheduled downtime	10.6%	N/A	N/A	
Number of users	400	400	400	0

[a] During FY 2013 through FY 2015, there will be no research hours to which the CEBAF facility will be held accountable while the 12 GeV upgrade is commissioned and reliability is expected to be low. In FY 2014, 14 weeks of beam development and tuning are supported as the facility comes back on from a prolonged shutdown. In FY 2015, approximately 16 weeks of machine development are supported. The user community is expected to remain active during the shutdown with instrumentation and equipment implementation for the upgraded facility so they continue to be shown in these years.

[b] The optimal hours at ATLAS in FY 2013–2015 vary due to downtime for installation of upgrades.

	FY 2013 Current	FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Total Scientific User Facility Operations	**$276,836**	**$300,203**	**$301,286**	**+$1,083**
Achieved operating hours	6,342	N/A	N/A	
Planned operating hours	5,600	6,270	8,670	+2,400
Optimal hours	8,300	8,300	10,300	+2,000
Percent of optimal hours (funding weighted)	59.5%	69.3%	70.7%	
Unscheduled downtime	27.8%	N/A	N/A	
Number of users	2,860	2,845	2,835	-10

Scientific Employment[a]

	FY 2013 Estimate	FY 2014 Estimate	FY 2015 Estimate	FY 2015 vs. FY 2014
Number of permanent Ph.D.'s (FTEs)	735	715	700	-15
Number of postdoctoral associates (FTEs)	320	300	285	-15
Number of graduate students (FTEs)	525	480	440	-40
Number of Ph.D.'s awarded	85	85	85	0

[a] This table does not include approximately 1,000 engineering, technical, and administrative FTEs that are supported by the NP program.

14-SC-50, Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU)
East Lansing, MI
Project is for a Cooperative Agreement

1. Significant Changes

This is a new project data sheet (PDS) resulting from the FY 2014 appropriation, which established a control point for the Facility for Rare Isotope Beams (FRIB). However, this PDS does not represent a new start for FRIB. Funds were appropriated for this project in FY 2009 through FY2013 within the Nuclear Physics Low Energy subprogram.

The most recent approved Critical Decision (CD) for the Facility for Rare Isotope Beams (FRIB) project is CD-2/3A (Approve Performance Baseline/Approve Start of Civil Construction) which was approved on August 1, 2013, with a DOE Total Project Cost (TPC) of $635,500,000 and CD-4 by 3Q FY 2022. In addition, Michigan State University (MSU) is providing a cost share of $94,500,000, bringing the total project cost to $730,000,000. FRIB is funded through a cooperative agreement financial assistance award with MSU per 10 CFR 600, and the project is required by this agreement to follow the principles of the DOE Order 413.3B. Funding tables contained in sections 3, 5, and 6 of this PDS differ slightly in how the baseline is presented from a traditional PDS for a federal capital asset construction project.

Following enactment of the FY 2014 appropriation, the Acquisition Executive authorized the start of civil construction. There are no changes in the scope, cost, and schedule since the establishment of this project's baseline on August 1, 2013.

A Federal Project Director has been assigned to this project.

2. Critical Decision (CD) and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	Design Complete	CD-2/3A	CD-3B	CD-4	D&D
FY 2011	2/9/2004	4Q FY 2010	TBD	TBD	TBD	FY 2017–2019	N/A
FY 2012	2/9/2004	9/1/2010	TBD	4Q FY 2012	TBD	FY 2018–2020	N/A
FY 2013	2/9/2004	9/1/2010	TBD	TBD	TBD	TBD	N/A
FY 2014	2/9/2004	9/1/2010	TBD	3Q FY 2013	TBD	TBD	N/A
FY 2015	2/9/2004	9/1/2010	4Q FY 2014[a]	8/1/2013	4Q FY 2014	3Q FY 2022	N/A[b]

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3A – Approve Start of Civil Construction
CD-3B – Approve Start of Technical Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

[a] This date represents when the design will be substantially complete to allow the start of technical construction (CD-3B). A limited amount of design effort will continue through 4Q FY 2017.
[b] MSU is responsible for the D&D of the facility.

3. Baseline and Validation Status[a]

(dollars in thousands)

	Design/ Construction	R&D/Conceptual Design/NEPA	Pre-Operations	Total TPC	Less MSU Cost Share	DOE TPC
FY 2015	655,700	24,600	49,700	730,000	-94,500	635,500

4. Project Description, Scope, and Justification

Mission Need

FRIB will provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics, and other topics in nuclear physics. This facility will impact the study of the origin of the elements and the evolution of the cosmos, and offers an opportunity for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a more broadly applicable theory of nuclei will emerge. The facility will offer new glimpses into the origin of the elements, leading to a better understanding of key issues by creating exotic nuclei that, until now, have existed only in nature's most spectacular explosion, the supernova.

Scope and Justification for 14-SC-50, Facility for Rare Isotope Beams (FRIB)

The science which underlies the FRIB mission is a core competency of nuclear physics: understanding how protons and neutrons combine to form various nuclear species; understanding how long chains of different nuclear species survive; and understanding how one nuclear species decays into another and what is emitted when that happens. Forefront knowledge and capability in this competency is essential, both for U.S. leadership in this scientific discipline and to provide the knowledge and workforce needed for numerous activities and applications relevant to national security and economic competitiveness.

FRIB is optimized to produce large quantities of a wide variety of rare isotopes by breaking stable nuclei into rare isotopes. High intensity primary beams of stable isotopes are produced in Electron Cyclotron Resonator (ECR) ion sources and accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator capable of delivering 400 kW of beam power at full energy. Secondary beams of rare isotopes are produced "in-flight" and separated from unwanted fragments by magnetic analysis. These rare isotope beams are delivered to experimental areas or stopped in a suite of ion-stopping stations where they can be extracted and used for experiments at low energy, or reaccelerated for astrophysical experiments or for nuclear structure experiments. The project includes the necessary infrastructure and support facilities for operations and the 1,000-person user community.

CD-4 Key Performance Parameters

System	Parameter	Performance Criteria
Accelerator System	Accelerate heavy-ion beam	Measure FRIB driver linac Argon-36 beam with energy larger than 200 MeV per nucleon and a beam current larger than 20 pico nano amps (pnA).

[a] Because this project is funded with operating dollars through a financial assistance award, its baseline is categorized through a work breakdown structure (WBS), which is slightly different from typical federal capital assets. Note that the project's WBS totals $730,000,000 including MSU's cost share. The WBS scope is not pre-assigned to DOE or MSU funds.

System	Parameter	Performance Criteria
Experimental Systems	Produce a fast rare isotope beam of Selenium-84	Detect and identify Selenium-84 isotopes in FRIB fragment separator focal plane
	Stop a fast rare isotope beam in gas and reaccelerate a rare isotope beam	Measure reaccelerated rare isotope beam energy larger than 3 MeV per nucleon
Conventional Facilities	Linac tunnel	Beneficial occupancy of subterranean tunnel structure of approximately 500 feet path length (minimum) to house FRIB driver linear accelerator
	Cryogenic helium liquefier plant—building and equipment	Beneficial occupancy of the cryogenic helium liquefier plant building and installation of the helium liquefier plant complete
	Target area	Beneficial occupancy of target area and one beam line installed and ready for commissioning

As contractually required under the financial assistance award agreement, FRIB is being conducted in accordance with the project management principles in DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

5. Financial Schedule[a]

(dollars in thousands)

	Appropriations	Obligations	Costs
DOE Total Project Cost (TPC)			
FY 2009	7,000	7,000	1,874
FY 2010	12,000	12,000	13,838
FY 2011	10,000	10,000	13,288
FY 2012	22,000	22,000	19,506
FY 2013	22,000	22,000	22,260
FY 2014[b]	55,000	55,000	57,234
FY 2015	90,000	90,000	90,000
FY 2016	100,000	100,000	100,000
FY 2017	100,000	100,000	100,000
FY 2018	97,200	97,200	97,200
FY 2019	75,000	75,000	75,000
FY 2020	40,000	40,000	40,000
FY 2021	5,300	5,300	5,300
Total, DOE TPC	635,500	635,500	635,500

[a] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.
[b] This is the first project data sheet submitted for FRIB. It was established as a control point in the FY 2014 appropriation. Funding for the project in FY 2013 and prior years was provided within the Low Energy subprogram.

6. Details of Project Cost Estimate[a]

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Design & Construction			
Management and Support	35,200	N/A	35,200
Conventional Facilities	165,300	N/A	165,300
Accelerator Systems	241,400	N/A	241,400
Experimental Systems	55,000	N/A	55,000
Contingency (DOE Held)	158,650	N/A	158,650
Total, Design & Construction	655,700	N/A	655,700
Contingency, Design & Construction (DOE Held)	158,650	N/A	158,650
Other Costs			
Conceptual Design/Tech R&D/NEPA	24,600	N/A	24,600
Pre-ops/Commissioning/Spares	35,500	N/A	35,500
Contingency (DOE Held)	14,150	N/A	14,150
Total, Other Costs	64,100	N/A	64,100
Contingency, Other Costs (DOE Held)	14,150	N/A	14,150
Total, TPC	730,000	N/A	730,000
Less MSU Cost Share	-94,500	N/A	-94,500
Total, DOE TPC	635,500	N/A	635,500
Total, Contingency (DOE Held)	172,800	N/A	172,800

[a] This section shows a breakdown of the total project cost of $730,000,000, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.

7. Schedule of Appropriation Requests[a]

(dollars in thousands)

Request Year		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	Outyears	Total
FY 2011	TPC	29,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2012	TPC	59,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2013	TPC	51,000	22,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014	TPC	51,000	22,000	55,000	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015 PB[b]	TPC	51,000	22,000	55,000	90,000	100,000	100,000	97,200	120,300	635,500

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	2Q FY2022
Expected Useful Life	20 Years
Expected Future Start of D&D of this capital asset	NA[c]

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations[d]	90,000	N/A	1,800,000[e]	N/A

9. Required D&D Information

The FRIB project is being constructed at MSU under a cooperative agreement financial assistance award. The one-for-one requirement is not applicable, since this is not a federal capital acquisition. MSU is responsible for the D&D of the facility.

10. Acquisition Approach

FRIB project activities, such as the construction of conventional facilities, will be accomplished following all procurement requirements, which include using fixed-priced competitive contracts with selection based on best value. MSU has contracted for the services of an architect-engineer firm for the design of the conventional facilities. The Driver Linac and Experimental System components will be self-performed by the MSU design staff with assistance from outside vendors and from DOE national laboratories that possess specific areas of unique expertise unavailable from commercial sources.

[a] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.
[b] The Performance Baseline was approved August 1, 2013. This is the first project data sheet submitted for FRIB. It was established as a control point in the FY 2014 appropriation. Funding for the project prior to that time was provided within the Low Energy subprogram.
[c] Per the financial assistance award agreement, MSU is responsible for D&D.
[d] Utilities, maintenance, and repair costs are included within the Operations amounts.
[e] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $90,000,000 (including escalation) over 20 years.

Integration of the conventional facilities with the Driver Linac and Experimental Systems will be accomplished by the MSU FRIB Project Team.

06-SC-01, 12 GeV CEBAF Upgrade, Thomas Jefferson National Accelerator Facility
Newport News, Virginia
Project is for Design and Construction

1. Summary and Significant Changes

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, which was signed on September 15, 2008, with a Total Project Cost (TPC) of $310,000,000 and a planned CD-4, Approve Project Completion, in the third quarter of FY 2015. A baseline change was required as a result of the FY 2012 appropriation which provided $16,000,000 less than the baseline profile. Because of this directed change and technical and performance challenges associated with the procurement of seven superconducting magnets, the project underwent several reviews during FY 2013 to rebaseline the project's cost and schedule. A baseline change was approved on September 4, 2013, and is reflected in this project datasheet. It increases the TPC by $28,000,000 to a total of $338,000,000, and extends the project CD-4B completion date by 27 months to September 2017. There are no changes to the original performance deliverables established at CD-2. Risks continue to be closely monitored, and include challenges with the procurement and installation of components, schedule, and impacts of funding uncertainty. For each moderate and high risk, a mitigation plan is developed in order to optimize successful project completion

The Federal Project Director (FPD) continues to be mentored as he works from his current Level 2 certification toward certification Level 3, anticipated by the Summer of 2014,.

This project data sheet (PDS) does not include a new start for the budget year; it is an update of the FY 2014 PDS.

2. Critical Decision (CD) and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	Design Complete	CD-2	CD-3	CD-4A	CD-4B	D&D
FY 2007	3/31/2004	1Q FY 2007	4Q FY 2009	4Q FY 2007	4Q FY 2008	N/A	1Q FY 2014	N/A
FY 2008	3/31/2004	2/14/2006[a]	4Q FY 2009	4Q FY 2007	4Q FY 2008	N/A	1Q FY 2015	N/A
FY 2009	3/31/2004	2/14/2006	4Q FY 2009	11/9/2007	4Q FY 2008	N/A	3Q FY 2015	N/A
FY 2010	3/31/2004	2/14/2006	4Q FY 2009	11/9/2007	9/15/2008	1Q FY 2015	3Q FY 2015	N/A
FY 2011	3/31/2004	2/14/2006	1Q FY 2010	11/9/2007	9/15/2008	1Q FY 2015	3Q FY 2015	N/A
FY 2012	3/31/2004	2/14/2006	12/31/2009	11/9/2007	9/15/2008	1Q FY 2015	3Q FY 2015	N/A
FY 2013	3/31/2004	2/14/2006	12/31/2009	11/9/2007	9/15/2008	1Q FY 2015	3Q FY 2015	N/A
FY 2014[b]	3/31/2004	2/14/2006	12/31/2009	11/9/2007	9/15/2008	1Q FY 2015	3Q FY 2015	N/A
FY 2015	3/31/2004	2/14/2006	12/31/2009	11/9/2007	9/15/2008	1Q FY 2015	4Q FY 2017	N/A

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline

[a] CD-1 was approved on 2/14/2006. Engineering and design activities started in 4Q FY 2006 after Congress approved the Department of Energy's request to reprogram $500,000 within the FY 2006 funding for Nuclear Physics, per direction contained in H.Rpt 109–275.
[b] The CD-4B date did not reflect the impact resulting from the reduced FY 2012 funding, which has since been assessed in a rebaseline in FY 2013 and is reflected in the FY 2015 data in this table.

CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D– Demolition & Decontamination (D&D) work

3. Baseline and Validation Status

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2007	21,000	TBD	TBD	11,000	TBD	TBD	TBD
FY 2008	21,000	TBD	TBD	10,500	TBD	TBD	TBD
FY 2009	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2010	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2011	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2012	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2013	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2014	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2015[a]	21,000	289,500	310,500	27,500	N/A	27,500	338,000

4. Project Description, Scope, and Justification

Mission Need

The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility is the world-leading facility for the experimental study of the structure of matter governed by the "strong force." An energy upgrade of CEBAF was identified by the nuclear science community as a compelling scientific opportunity. In particular, the Nuclear Science Advisory Committee (NSAC) stated in the 1996 Long Range Plan that "…the community looks forward to future increases in CEBAF's energy, and to the scientific opportunities that would bring." In the 2007 Long Range Plan, NSAC concluded that completion of the 12 GeV CEBAF Upgrade project was the highest priority for the Nation's nuclear science program.

Scope and Justification for 06-SC-01, 12 GeV CEBAF Upgrade

The 12 GeV CEBAF Upgrade directly supports the Nuclear Physics mission and addresses the objective to measure properties of the proton, neutron, and simple nuclei for comparison with theoretical calculations to provide an improved quantitative understanding of their quark substructure.

The scope of the project includes upgrading the electron energy capability of the main accelerator from 6 GeV to 12 GeV, building a new experimental hall (Hall D) and associated beam-line, and enhancing the capabilities of the existing experimental halls to support the most compelling nuclear physics research.

[a] The amounts reflect the revised baseline approved in September 2013. A Work-for-Others agreement was approved by DOE that provides $9,000,000 appropriated by the Commonwealth of Virginia to leverage the federal investment for an upgrade of the Jefferson Lab's research facilities. This funding is outside the DOE baseline cost and schedule.

CD-4A Key Performance Parameters

Subsystem	Technical Definition of Completion
Accelerator	12 GeV capable 5.5 pass machine installed
	11 GeV capable beam line to existing Halls A, B, and C installed
	12 GeV capable beam line to new Hall D tagger area installed
	Accelerator commissioned by transporting a ≥ 2 nA electron beam at 2.2 GeV (1pass)
Conventional Facilities	New Experimental Hall D and the Counting House: ≥ 10,500 square feet.

CD-4B Key Performance Parameters

Subsystem	Technical Definition of Completion
Hall B	Detector operational: events recorded with a ≥ 2 nA electron beam at > 6 GeV beam energy (3 pass)
Hall C	Detector operational: events recorded with a ≥ 2 nA electron beam at > 6 GeV beam energy (3 pass)
Hall D	Detector operational: events recorded with a ≥ 2 nA electron beam at > 10 GeV beam energy (5.5 pass)

Key Performance Parameters to achieve CD-4 are phased between the accelerator and conventional facilities (CD-4A) and the experimental equipment in Halls B, C, and D (CD-4B). The deliverables defining completion are identified in the Project Execution Plan and have not changed since CD-2. Mitigation plans exist for identified risks to help ensure successful project completion after approval of a baseline change proposal due to the directed change and technical challenges.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements have been met.

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
Total Estimated Cost (TEC)				
Design				
FY 2006	500	500	0	88
FY 2007	7,000	7,000	0	6,162
FY 2008	13,377[a]	13,377	0	9,108
FY 2009	123[a]	123	0	5,370
FY 2010	0	0	0	265
FY 2011	0	0	0	7
Total, Design	21,000	21,000	0	21,000

[a] The baseline FY 2008 PED funding was reduced by $123,000 as a result of a FY 2008 rescission. This reduction was restored in FY 2009 to maintain the TEC and project scope.

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
Construction				
FY 2009	28,500	28,500	0	5,249
FY 2009 Recovery Act	65,000	65,000	2,738	0
FY 2010	20,000	20,000	29,621	18,642
FY 2011[a]	35,928	35,928	25,890	40,801
FY 2012	50,000	50,000	5,203	45,537
FY 2013	40,572	40,572	1,545	51,211
FY 2014	25,500	25,500	3	27,060
FY 2015	16,500	16,500	0	21,500
FY 2016	7,500	7,500	0	12,500
FY 2017	0	0	0	2,000
Total, Construction	289,500	289,500	65,000	224,500
TEC				
FY 2006	500	500	0	88
FY 2007	7,000	7,000	0	6,162
FY 2008	13,377	13,377	0	9,108
FY 2009	28,623	28,623	0	10,619
FY 2009 Recovery Act	65,000	65,000	2,738	0
FY 2010	20,000	20,000	29,621	18,907
FY 2011	35,928	35,928	25,890	40,808
FY 2012	50,000	50,000	5,203	45,537
FY 2013	40,572	40,572	1,545	51,211
FY 2014	25,500	25,500	3	27,060
FY 2015	16,500	16,500	0	21,500
FY 2016	7,500	7,500	0	12,500
FY 2017	0	0	0	2,000
Total, TEC	310,500	310,500	65,000	245,500

[a] The baseline FY 2011 funding was reduced by $72,000 as a result of a FY 2011 rescission.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs
Other Project Cost (OPC)				
OPC except D&D				
FY 2004	700	700	0	77
FY 2005	2,300	2,300	0	2,142
FY 2006	4,000	4,000	0	3,508
FY 2007	2,500	2,500	0	2,751
FY 2008	1,000	1,000	0	1,802
FY 2009	0	0	0	155
FY 2010	0	0	0	62
FY 2013	2,500	2,500	0	2,178
FY 2014	4,500	4,500	0	4,425
FY 2015	4,500	4,500	0	4,500
FY 2016	4,500	4,500	0	4,500
FY 2017	1,000	1,000	0	1,400
Total, OPC	27,500	27,500	0	27,500
Total Project Cost				
FY 2004	700	700	0	77
FY 2005	2,300	2,300	0	2,142
FY 2006	4,500	4,500	0	3,596
FY 2007	9,500	9,500	0	8,913
FY 2008	14,377	14,377	0	10,910
FY 2009	28,623	28,623	0	10,774
FY 2009 Recovery Act	65,000	65,000	2,738	0
FY 2010	20,000	20,000	29,621	18,969
FY 2011	35,928	35,928	25,890	40,808
FY 2012	50,000	50,000	5,203	45,537
FY 2013	43,072	43,072	1,545	53,389
FY 2014	30,000	30,000	3	31,485
FY 2015	21,000	21,000	0	26,000
FY 2016	12,000	12,000	0	17,000
FY 2017	1,000	1,000	0	3,400
Total, TPC[a]	338,000	338,000	65,000	273,000

[a] The TPC reflects the revised baseline approved in September 2013.

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Estimate
Total Estimated Cost (TEC)			
Design			
Design	21,000	21,000	19,200
Contingency	0	0	1,800
Total, Design	21,000	21,000	21,000
Construction Phase			
Construction	30,347	30,306	27,450
Accelerator/Experimental Equipment/Management	243,937	225,059	174,150
Contingency	15,216	11,135	64,900
Total, Construction	289,500	266,500	266,500
Total, TEC	310,500	287,500	287,500
Contingency, TEC	15,216	11,135	66,700
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Design	3,445	3,445	3,500
R&D	7,052	7,052	6,400
Start-up	12,618	11,836	7,450
Contingency	4,385	167	5,150
Total, OPC	27,500	22,500	22,500
Contingency, OPC	4,385	167	5,150
Total, TPC	338,000[a]	310,000	310,000
Total, Contingency	19,601	11,302	71,850

[a] The TPC reflects the revised baseline approved in September 2013.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Total
FY 2007 (Design only)	TEC	21,000	0	0	0	0	0	0	0	0	21,000
	OPC	11,000	0	0	0	0	0	0	0	0	11,000
	TPC	32,000	0	0	0	0	0	0	0	0	32,000
FY 2008 (Design only)	TEC	21,000	0	0	0	0	0	0	0	0	21,000
	OPC	10,500	0	0	0	0	0	0	0	0	10,500
	TPC	31,500	0	0	0	0	0	0	0	0	31,500
FY 2009[a] PB	TEC	49,500	59,000	62,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	60,000	59,000	62,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2010[b]	TEC	114,500	22,000	34,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	22,000	34,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2011	TEC	114,500	20,000	36,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	20,000	36,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2012	TEC	114,500	20,000	36,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	20,000	36,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2013	TEC	114,500	20,000	35,928[c]	50,000	40,572	26,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	20,000	35,928	50,000	43,072	34,000	2,000	0	0	310,000

[a] The FY 2009 Congressional Budget was the first project data sheet to reflect the CD-2 Performance Baseline which was approved in November 2007.

[b] The project received $65,000,000 from the American Recovery and Reinvestment Act of 2009 which advanced a portion of the baselined FY 2010 and FY 2011 planned funding. The FY 2010 and FY 2011 amounts reflect a total of $65,000,000 in reductions to the originally planned baselined funding profile to account for the advanced Recovery Act funding.

[c] The baseline FY 2011 funding was reduced by $72,000 as a result of the FY 2011 rescission.

(dollars in thousands)

Request Year		Prior Years	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Total
FY 2014	TEC	114,500	20,000	35,928	50,000	50,306	25,500	1,000	0	0	287,500
	OPC	10,500	0	0	0	—	4,500	5,000	0	0	22,500
	TPC[a]	125,000	20,000	35,928	50,000	50,306[b]	30,000	6,000	0	0	310,000
FY 2015	TEC	114,500	20,000	35,928	50,000	40,572	25,500	16,500	7,500	0	310,500
	OPC	10,500	0	0	0	2,500	4,500	4,500	4,500	1,000	27,500
	TPC[c]	125,000	20,000	35,928	50,000	43,072	30,000	21,000	12,000	1,000	338,000

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2017
Expected Useful Life (number of years)	15
Expected Future start of D&D for new construction (fiscal quarter)	N/A

<u>(Related Funding Requirements)</u>

(dollars in thousands)

	Annual Costs		Life cycle costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	150,000	150,000	2,250,000[d]	2,250,000
Maintenance	Included above	Included above	Included above	Included above
Total, Operations & Maintenance	150,000	150,000	2,250,000	2,250,000

[a] The TPC did not reflect the estimated impact resulting from the reduced FY 2012 funding, which has since been assessed and a rebaseline was approved in September 2013.

[b] The FY 2013 amount shown reflected the P.L. 112-175 continuing resolution level annualized to a full year. The TEC, TPC, and outyear appropriation assumptions had not been adjusted to reflect the final FY 2013 funding level; the FY 2013 Request level of $40,572,000 for TEC, $2,500,000 for OPC, and $43,072,000 for TPC was assumed.

[c] The TPC reflects the revised baseline approved in September 2013.

[d] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $150,000,000 (including escalation) over 15 years. Almost 90% of the O&M cost would still have been required had the existing accelerator not been upgraded and instead continued operations at 6 GeV.

9. Required D&D Information

	Square Feet
Area of new construction	31,500
Area of existing facility(ies) being replaced and D&D'd by this project	0
Area of other D&D outside the project	0
Area of additional D&D space to meet the "one-for-one" requirement taken from the banked area.	31,500

The "one-for-one" requirement is met by offsetting 31,500 square feet of the 80,000 square feet of banked space that was granted to Jefferson Laboratory in a Secretarial waiver.

10. Acquisition Approach

The Acquisition Strategy was approved February 14, 2006 with CD-1 approval. All acquisitions are managed by Jefferson Science Associates with appropriate Department of Energy oversight. Cost, schedule, and technical performance are monitored using an earned-value process that is described in the Jefferson Lab Project Control System Manual and consistent with DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets. The procurement practice uses firm fixed-price purchase orders and subcontracts for supplies, equipment, and services and makes awards through competitive solicitations. Project and design management, inspection, coordination, tie-ins, testing and checkout witnessing, and acceptance are performed by Jefferson Laboratory and Architectural-Engineering subcontractors as appropriate.